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Global Change Video: Visualization Freeze-Frames

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Global change—both natural and anthropogenic—rouses serious national and international concern. Although civilian satellites cannot currently monitor human activity at the human scale, earth-orbiting platforms record its increasing impact. For vast inaccessible regions, such as Antarctica, earth-observing satellites provide the only means for monitoring the environment.

As television viewers, we have all become used to the role of satellites in monitoring the changing weather. The *Global Change Video* (*GCV*) aims to communicate changes recorded by satellites in an easily interpretable form that is nevertheless scientifically accurate. We hope this will help people with no background in scientific visualization to identify change easily.

The complex iconography developed by visualization specialists might communicate detailed observations and simulations well to fellow scientists, but it leaves the rest of the world out in the cold. We want to maximize communication by using natural analogs of visual function and the world outside our laboratory windows to display scientific data.

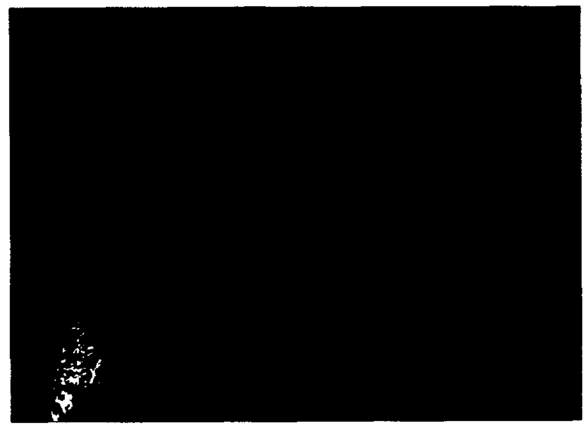

Figure 1. Earth viewed over the Americas using ImagingBase, rendered with a texture-mapped *z*-buffer.

Satellites

Daily over the last decade, the American National Oceanographic and Atmospheric Administration (NOAA) satellite-based Advanced Very High Resolution Radiometer (AVHRR) instrument has systematically collected global pictures at 4.4 km resolution. Over the last 20 years, the U.S. National Aeronautics and Space Administration (NASA) Landsat satellite has collected data at 30m and 80m resolution, with a longer time between overhead passes (currently 16 days). The French Systémè Probatorie d' Observations de la Terre (SPOT) satellite allows collection of across-track 10m stereo data, while the Japanese ERS-1 now allows along-track stereo at 18m resolution. Finally, the European ERS-1 satellite collects 1km stereo data of the cloud tops. Researchers can use this stereo data to retrieve[1] the 3D surface of the land or of clouds as well as microwave interferograms.

In addition to these surface-observing satellites, various earth-orbiting satellites measure minute traces of different chemical species. Most important is ozone, because of its long-term role in controlling the amount of harmful ultraviolet radiation that reaches Earth's surface.

Global Change Video

Promoting the role of earth-observing satellites in monitoring global change was a key part of the 1992 International Space Year Global Change Outreach program. We proposed to the German, British, and European Space Agency (ESA) a 10-minute videofilm of computer-generated animations to be called the *Global Change Video*. It would demonstrate various global change themes using satellite data to the general public. Twenty-one agencies submitted global or regional data sets according to the themes we requested. Of those, we selected 19 data sets.

At this writing, we have completed three different products: an interactive videodisk called *Erd-Sicht (Earth View) Global Change*, which includes 15 minutes of 3D animations; an 11-minute videofilm largely derived from it; and 29 minutes of video animation in 18 different video segments (14 3D animations from University College London and four 2D animations from DLR). A number of derivative works are currently under discussion.

The total estimated CPU time for rendering these animations, including large amounts of preprocessing of the 40 Gbytes of input data, is 16 CPU years of Sparcstation time.[2] We used distributed processing on a network of Sun and Silicon Graphics workstations.

The *Erd-Sicht* video installation is the major part of an 18-installation exhibit held at the newly opened National Art and Exhibition Center of the Federal Republic of Germany in Bonn. From its opening in June 1992 to its close on March 21, 1993, more than half a million people visited the exhibition. The installation consisted of an interactive computer-based multimedia system produced by MultiMedia, London, incorporating an Apple Macintosh computer with a touch screen and a

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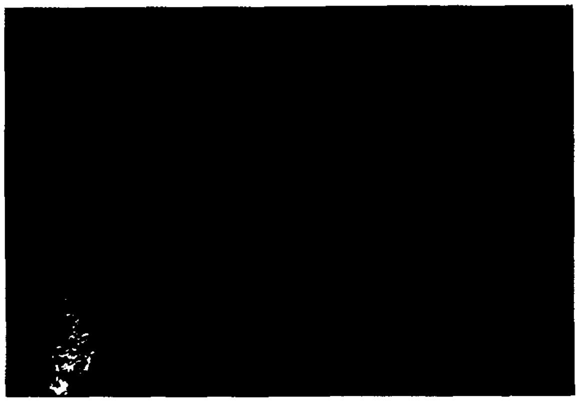

Figure 2. 3D display of the same globe as in Figure 1, with ray-traced haze composited.

high-resolution digital frame store, three video projection screens, compact disk audio, and two videodisk players.

The *Earth Environment Flyby* allows visitors to fly more than a thousand times the speed of sound above the Earth's surface. From that perspective they select various stories about global change. We illustrated the stories using multiresolution, multitemporal satellite data and numerical simulations, as well as library footage from different television sources. Viewers can select narration and titling in either German or English. They can choose spin-offs from the simulated three-minute cloverleaf flight around the Earth either using on-screen icons during the flight or a "control panel" touch-icon menu.

We chose video as a display medium because of the enormous computation times and massive data-set sizes, which current hardware systems cannot render at video refresh frequencies. We visualized four stories of natural change: Antarctic sea ice, vegetation throughout Africa, the volcanic explosion of Mt. Pinatubo, and plankton (coccolith) blooms. In addition, we visualized eight stories involving change brought about by human activities: the Gulf War, ozone depletion, Aral Sea shrinkage, deforestation in Brazil, urbanization in the U.S. and Egypt, simulated sea-level rise in the northern German plain, changing energy uses in Europe at night, and the demise of forests in Central Europe from atmospheric pollution (Waldstarben).

The *Global Change Video* includes a multiresolution 3D flight through five different resolution data sets (from 9 km to 1 m); a number of rotating globes showing Earth, Mars (from Mariner 9), and Venus (from Magellan SAR); and a story of change involving a year in the life of Earth's clouds. We took all the figures shown here directly from *GCV* sequences.

UCL ImagingBase and photorealism

In late 1990 and early 1991, Muller and Eales compiled the UCL ImagingBase—a nearly cloud-free, photorealistically colorized mosaic of global, 1-km images. For sections over land, they used nearly 200 AVHRR images taken from different seasons between 1980 and 1990. For sections over the ocean, they colorized a global seven-year composite of ocean color compiled by Gene Feldman at the NASA Goddard Space Flight Center. For the area over sea ice, they employed data from the Defense Meteorological Satellite Program (DMSP) passive microwave instrument.

The colorization of the AVHRR mosaic and the resulting colorized ImagingBase was performed by, and is exclusively licensed for commercial applications to, GlobalVisions of Bolinas, California. We expect the noncolorized version will be available under license on CD-ROM from a U.S. government agency for scientific research applications late in 1993. Strict adherence to color standards means that the resulting colorized data closely resembles the actual appearance of Earth devoid of atmosphere.

The UCL ImagingBase forms the centerpiece of the 3D animations. We color-corrected all other data sets merged with it to ensure seamless inte-

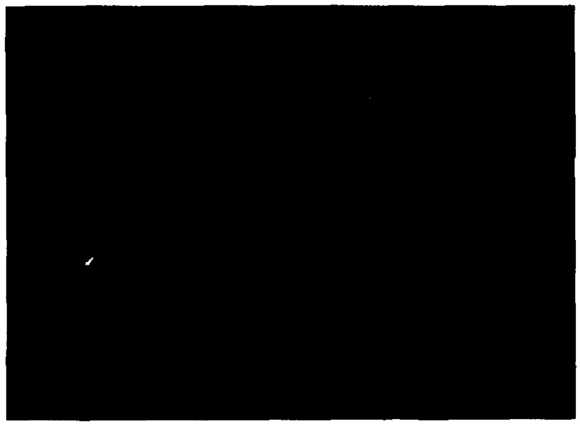

Figure 3. 3D display of the same globe as in Figure 2, with ray-traced clouds, terminator, specular (sun glint) sea highlights, and night lights.

gration of multiresolution data sets or time series data. AVHRR only has a single visible spectral band, so we obtained color information from other regions of the infrared spectrum.

Figures 1 through 3 show different examples of different techniques using the UCL ImagingBase to visualize the Earth. Figure 1 shows the use of a depth-buffer renderer written by David Rees. The renderer incorporates pyramidal texture mapping on a sphere, hierarchical polygon rendering, Lambertian reflectance functions, and spatial antialiasing. Figure 2 shows the use of a ray tracer written by Tim Day to generate a haze layer and composite this layer with the depth-buffered texture map. Figure 3 shows this ray tracer used for the application of specular reflectance function, cloud layer transparency, and ray casting.

We can use compositing to combine different z-buffer or ray tracings using color, depth, transparency, and time. Time compositing allows us to visualize change using linear interpolation.

Animation

To design 3D animation, we used the Wavefront Preview system with a globe wireframe and a global vector coastline

Figure 4. 3D smoke clouds from the Kuwait oil fires lit by retreating Iraqi forces. Cloud-top height modeled using the thermal infrared signature from Landsat and in situ measurements taken after the end of the Gulf War.

decimated (reduced in resolution by taking every *n*th segment) from the U.S. Navy World Vector Shoreline. We used other wireframe representations of texture maps as appropriate.

For animation we used 3D snapshots where insufficient temporal sampling prohibits in-fill linear interpolation (such as clouds and smoke): cross-fade sequences where interpolation would lead to inaccurate representations of what happened between the frames; spatial interpolations, including the in-fill of missing data (in-betweened using actual data): and the mixing of modeled data (such as sea-level rise) over time with a static or moving viewpoint over single or multiple texture maps.

Applications

Figure 4 shows an example of a 3D snapshot of Kuwaiti oil-fire smoke. The still is at the end of a multiresolution flight in the *Earth Environment Flyby*, coming down and around the smoke plumes. We extracted the smoke plumes using the Landsat thermal channel by inverting the black-body thermal infrared temperature signature with a model of the inversion layer.

Figure 5 shows the use of a natural analog for UV absorption by ozone. Transparency is inversely related to the Dobson Unit. This still is part of a time-interpolated sequence derived from the Total Ozone Mapping Spectrometer (TOMS) instrument. The ozone depletion area appears as a hole because the transparency function is maximized at the 50 percent depletion level. The narration ensures that viewers know they are looking at depletion, not total absence.

Figure 6 shows a freeze-frame from the three-year cycle of the monthly composited vegetation index (derived from the broadband spectral ratio of near infrared to visible radiation from AVHRR). We visualized vegetation phenology with green for the vegetation index. Linear time interpolation vividly illuminated the ebb and flow of the carbon cycle.

Future visions

As Earth system science matures, model resolutions will approach earth observational data. In tandem, the next generation of polar-orbiting platforms of the Earth Observing System (from ESA, NASA, and NASDA) will allow accurate retrieval of surface land-cover information and foster an understanding of the relationship between land cover and the color of the surface. When this happens, global change visualizations will possess a clarity barely possible today. Moreover, we can clearly demonstrate the future consequences of human inaction. We can then expect mass broadcast of easily interpreted visualizations of scientific phenomena.

On a technical front, the visualization tools described here are being combined with GIS functionality. Eventually, this will give people who are not remote-sensing specialists access to scientific and geographic information, freed from the pseudocolor iconography of commercial scientific visualization packages and the claustrophobic traditions of print-map "flat world" cartography. ❑

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Figure 5. 3D display of Earth over Antarctica with total ozone concentration represented as a semitransparent layer over the ImagingBase mosaic.

References

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Figure 6. 3D display of Earth over Africa with the vegetation index mapped as varying shades of green on the ImagingBase mosaic.